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POST-CRETACEOUS HISTORY OF THE MOUNTAINS OF CENTRAL WESTERN WYOMING

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PART III

Quaternary cycles of stream erosion.—Although in the higher mountains stream erosion was superseded at intervals by glaciation, over most of the district the Quaternary period was a time of continuous action by running water and its accessory agencies. The erosion history was accented, however, by several changes which rejuvenated the streams from time to time, and thus prevented the completion of the successive erosion cycles. Conceivable causes of such interruptions are: (*a*) a series of general uplifts; (*b*) the readjustment of stream grades on account of the removal of obstructions in the channels of the master rivers, or because of piracy in their lower courses; and (*c*) notable changes of climate.

Of these causative changes, those which were climatic should have produced more or less harmonious results simultaneously over the entire district. The same should have been true of the gentle elevatory movements, if they were uniform over wide areas. The two factors should differ in their results in that climatic changes would doubtless make themselves felt all over the district at the same time, and streams would then respond either by trenching their floodplains or by aggrading them. The changes would apparently take place simultaneously throughout the entire graded profiles of all the streams. The elevatory movements, however, if equal everywhere, would cause rejuvenation first in the lower courses of the streams, or, in this instance, outside the district. The phenomena due to elevation or depression would then migrate up the individual streams; in such cases the new cycle features of the lower courses would be distinctly older than those of the upper courses at any given time. If the surface of the district, instead of

being uniformly raised (relatively), was warped, then the readjustments of stream action and their results must have been more complex. Rejuvenation due to the removal of falls and rapids or to stream-piracy would be likely to cause changes in one valley system which would have no counterpart in the adjacent drainage basins.

Climatic change may well explain some of the minor rejuvenations, but apparently is incompetent to account for the cutting of valleys hundreds or even thousands of feet deep. Inasmuch as it is not only possible, but fairly probable, that several or even all of these changes have been at work, it is clear that the problem to be dealt with is by no means simple; it should be approached in a spirit of caution and without an expectation of solving it completely except after more detailed field studies. It is an observed fact that the topographic features in different parts of the district here considered, and even in entirely different drainage basins, are so similar in aspect, in order, and in relations as to suggest that each has passed through a similar history, owing to the operation of some widespread influence. These facts suggest either climatic changes or regional uplifts. There is no question as to the competence of uplifts to induce dissection to proportionate depths, but climatic changes competent to bring about the incision of valleys to depths of hundreds or even several thousands of feet, as is indicated by the canyons in the ranges of Wyoming, would have to be extraordinary in magnitude. For that reason the hypothesis of changes of level seems to me the more favored one, although it should not be inferred that the other influences are excluded from participation in a minor degree.

The work of interpreting the erosion history of such a district involves largely the recognizing and discriminating of surfaces produced during successive cycles and correlating these in chronological order. Although it is often possible to recognize mature and even young topographic forms of preceding cycles of erosion, the most readily recognized features are the broad graded surfaces or flood plains which normally become wider and wider as the cycle proceeds. In Wyoming, however, a careful discrimination must be made between remnants of old river-graded surfaces, and those

other flats and terraces which are normally developed by the stripping of weak strata from harder beds in horizontal position—a process which is peculiarly effective in dry wind-swept plains. This distinction must be made particularly in the broad basins such as the Wind River and Green River basins, where the Tertiary strata have been but little disturbed. It is necessary also to bear in mind that the graded surfaces, which constitute the immediate goal of all streams, are not level, either transverse to the main stream or parallel to it. Therefore remnants of the same graded surface generally do not have the same elevation in different parts of the district, even though there has been no subsequent warping; but such remnants should bear approximately the same general relation to each other as corresponding parts of the modern floodplains bear to each other.

The studies of Westgate and Branson, already noticed, show that in the Lander district the topographic features reveal a definite sequence of cycles which may eventually be extended to a much larger region. The existing topography suggests a declining series of phases, in which the earliest cycles proceeded to old age, the intermediate ones to maturity, and the later ones only to youth. This may well be more apparent than real, however, for if any of the early stages had gone no farther than youth, the evidence of their existence would have been destroyed in those later cycles which went farther toward completion. As I am still somewhat doubtful about the correlation of the features I have seen with those described by Westgate and Branson, I present in Table II an independent scheme of glacial stages and erosion cycles, not as a final list, but necessarily as a provisional one.

Below the elevated peneplain, which has already been described as probably of Pliocene age, I find evidence suggesting at least four cycles of erosion, one of which appears to be older than the oldest glacial drift, while the rest are more or less associated with glacial phenomena. The latest cycle, which is probably complex in detail, is represented by the inner valleys with existing floodplains and their immediate terraces. It was closely associated with the last glacial stage. The phenomena of the various cycles may now be discussed more fully.

Fremont cycle: The oldest cycle recognized, of which the visible result was the "Wind River peneplain," may for the sake of uniformity be called the Fremont cycle, from the fact that the principal remnants of the Wind River plateau (Figs. 12-15) may be overlooked from Fremont Peak. In the Wind River Range the remnants of this surface attain elevations of 11,300 to over 12,000 feet, and in adjacent regions to the west other remnants supposed to be of the same age are between 10,500 and 11,000 feet above sea-level. Its features have been sufficiently described in *Jour. Geol.*, XXIII (1915), 193-94.

TABLE II

Epoch	Erosion Cycles (Largely Interglacial)	Glacial Stages	Stages according to Westgate and Branson
Recent	Post-glacial		Late glacial and terraces
Pleistocene		Pinedale	
	Lenore		
		Bull Lake	Early glacial
	Circle		Plain No. 1
		Buffalo	
	Black Rock		Plain No. 2
	Union Pass		Plains Nos. 3 and 4
Pliocene	Fremont		Summit peneplain

Union Pass cycle: The next stage in the denudation is typically represented by a post-mature surface cut upon the resistant Archean and Paleozoic rocks near the west end of the Wind River Range notably below the summit peneplain. It is evidenced by the broad, shallow, and well-graded valleys with elevations of from 9,000 to 9,500 feet at Union Pass and west of Sheep Mountain. East of Kendall, Little Flat-Top Mountain, of about the same elevation, is a beveled remnant of highly inclined Cretaceous rocks. Along the northeast slope of the Wind River Range, aged topographic forms high up on the mountain sides probably represent

this cycle, although the correlation is not assured. At the south-east end of the range, Westgate and Branson¹ distinguish two erosion cycles beneath the summit peneplain and higher than the cycle represented by Table Mountain near Lander, which I have tentatively correlated with the Blackrock cycle, farther east; these do not appear to be as distinct in the region I have studied, and were not recognized.

Still farther westward, there are, at a comparable elevation, broad, open, and well-graded valley heads both east and west of Twogwotee Pass, but always deeply intrenched farther downstream. Aged forms of similar aspect and relations have been observed between the valleys of Jack Pine and Conant creeks in the northwest part of the Teton Range. This gently sloping surface lies decidedly higher than the oldest deposits of glacial drift, but is a thousand feet or more below the tabular remnant interpreted as possibly part of the Goat Flat peneplain. In fact, the whole western slope of the Teton Range in the vicinity of the north fork of Pierre's River is a gently inclined plain rising from the general plateau level of about 6,000 feet to the bases of the more rugged peaks at 9,000-9,500 feet. Although it has been incised by deep canyons, there are still broad smooth remnants on the divides. The fact that the canyons are much deeper near their heads than farther west suggests that the surface has been tilted by being raised on the east. Although it is underlain by rocks of various types and structures, the plain is but little modified by structure.

At the west end of the Gros Ventre Range a few miles northeast of Jackson, there are rather large remnants of an ancient gentle valley slope cut across folded Paleozoic rocks. These remnants stand nearly 2,000 feet above the channels of the present streams.

No doubt the surface produced in the Union Pass cycle was broadly planed on the weak Mesozoic and Tertiary clays, although only late mature topography developed on the harder rocks near the headwaters of the streams, and some remnants of the summit peneplain were left untouched. In this cycle the latter was

¹ L. G. Westgate and E. B. Branson, "Cenozoic History of the Wind River Mountains," *Jour. Geol.*, XXI (1913), 142-59.

probably reduced very nearly to its present remnants, although its relative elevation has since been greatly increased.

Black Rock cycle: The next cycle has been named after Black Rock Meadows, near the head of one branch of Snake River, which at that point has excavated a flat-bottomed valley with gentle slopes chiefly on Mesozoic strata. Farther downstream, the flat is trenched and appears as a series of flat-topped spurs. These features lie several hundred feet lower than the valleys representing the Union Pass cycle in the vicinity. More or less generally throughout the district, the Black Rock valleys and remnants are 500–800 feet above the present stream. Along the Gros Ventre River, the cycle is probably represented by the long flat-topped spurs from one to eight miles below the mouth of Fish Creek. The surfaces of these spurs truncate Cretaceous beds which dip from 15° to 25° , and if the intervening gulches were filled there would be a continuous graded valley floor several miles wide. On one of the remnants a thin capping of water-worn gravel is still preserved. Corresponding features may be found in the tabular areas and flat gravelly spurs which obstruct the Snake River valley below Jackson Hole at elevations of 500–600 feet above the river, and the similar forms in the lower Snake River valley near Irwin, Idaho. These forms are apparently remnants of a wider, flat-bottomed valley much shallower than the present canyon of Snake River. In the Teton Range the wide shallow valleys of similar nature, from 500 to 1,000 feet above the bottoms of the modern canyons, suggest the same cycle.

Returning eastward to the north side of the Wind River basin, we find around Black Mountain (see Fig. 24), and westward along the mountains to DuNoir River, a high plain, distinctly lower than the Union Pass cycle, and now much dissected. Most of these remnants are veneered with weathered stream-gravel which plainly indicates the origin of the plain. At the mouth of each ravine in the mountain side, an old alluvial fan is still to be seen although nearly all such fans have been dissected. In some places in this district there is evidence that there are really two plains separated by a terrace 50–100 feet high, but in general there is not sufficient basis available for resolving the Black Rock cycle into two. In the

center of the basin the tributaries have largely destroyed the plain, leaving only small mesas or isolated buttes such as Crowheart Butte.

Around Lander and the southeast end of the Wind River Range, there are mesas and shelves along the foothills cut across inclined strata, at elevations of 600-700 feet above the present streams (Figs. 30, 31, 32). These are considered by Westgate as remnants of his plain No. 2, and they also have the characteristics and relations appropriate to the Black Rock cycle as defined in preceding

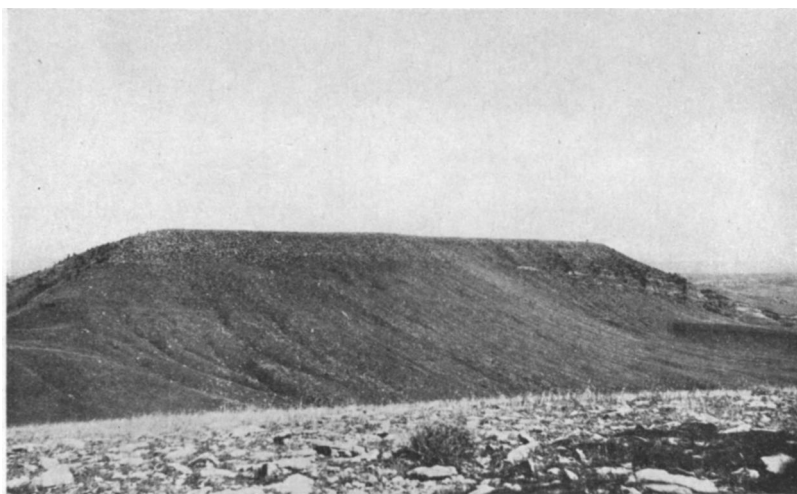


FIG. 30.—Table Mountain, near Lander. A mesa cut on tilted strata and capped with gravel. (Photograph by D. D. Condit, U.S. Geological Survey.)

pages. The layer of coarse gravel 50-250 feet thick in places, forming the top of each of these remnants, has interested geologists since the time of the Hayden Survey. On account of the fact that a few of the boulders are as much as 25 feet in diameter, and many of them 5-10 feet thick, it has been suggested that the deposit must be glacial. Westgate, however, cites the distinct although crude stratification of the material as evidence that it is stream-laid. Even larger boulders have been carried out from the canyons of the Sierra Nevada by torrents.¹ The hypothesis that these

¹ A. C. Trowbridge, *Jour. Geol.*, XIX (1911), 706-47.

patches of gravel near Lander are remnants of torrential fans agrees with the evidence so far as I have seen it.

In the Owl Creek Range also features indicating the Black Rock cycle have been observed although but sparingly. South of Anchor certain shoulders 600–800 feet above the valley bottoms are strewn with coarse, deeply weathered gravel and bowlders, which were once water-worn. There is considerable resemblance between conditions here and near Lander. In the upper course of Green River

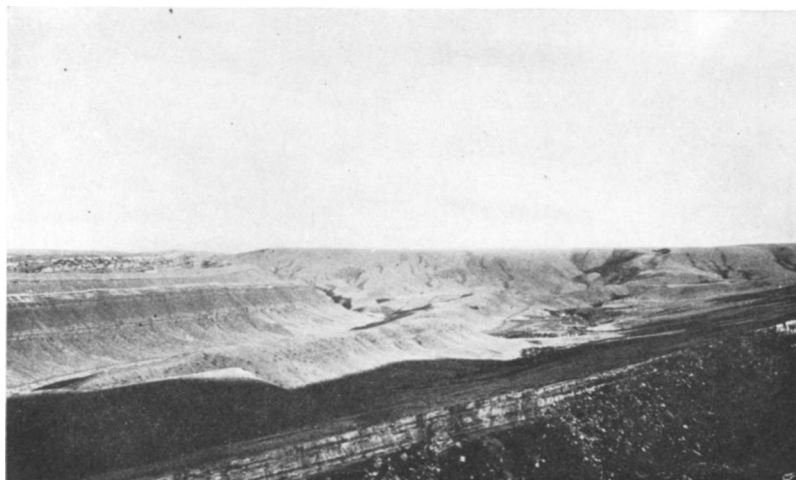


FIG. 31.—Tabular divide about twenty miles south of Lander. Probably represents the Black Rock cycle. Hogbacks of Permo-Mesozoic strata in the foreground. (Photograph by D. D. Condit, U.S. Geological Survey.)

similar high buttes and mesas, such as Flat Top Mountain near Kendall, suggest the same cycle.

In the type locality, the Buffalo old drift seems to lie always upon the remnants of Black Rock valley floors, and in the Teton Range the relations are similar. From these facts I infer that these shallow older valleys were completed about the time of the first well-recognized stage of glaciation in western Wyoming. It is a persistent and distinctive characteristic of the Black Rock surface that it is floored with thick and very coarse gravel deposits. None of the earlier or later partial plains of the region carry more than a thin veneer of such material. It has been suggested that the

coarse, stratified gravel deposits represent outwash from the ancient glaciers rather than torrential fan deposits under the influence of an epoch of desiccation. With reference to deposits now so deeply weathered, I know of no criteria that could be used to decide between these two modes of deposition. Whatever the origin, there is a suggestive resemblance between these thick coarse gravel deposits on remnants of the Black Rock plain and similar deposits in other ranges of the Rocky Mountains, such as the conglomerate



FIG. 32.—High rock-cut terrace southwest of Lander. The Carboniferous strata have been planed off at the level of Table Mountain (see Fig. 30).

of Bald Ridge on the east side of the Bighorn Range,¹ the Bishop conglomerate of southwestern Wyoming,² and other well-known examples.

Between the Black Rock cycle and the next one clearly discriminated there may well have been one or more cycles now represented by terraces visible here and there in the Wind River and Green River bad lands. These are, however, but little known and

¹ U.S. Geol. Survey, *Cloud Peak-Fort McKinney Folio*, No. 142.

² J. L. Rich, *Jour. Geol.*, XVIII (1910).

appear not to have left notable marks in any but the softest strata. For the present, therefore, they must be neglected.

Circle cycle: Benches cut across folded rocks along the sides of the mountain valleys and much wider terraces and mesas cut in the Tertiary basin are relics of a surface carved out of the Black Rock peneplain. Near the mouth of Fish Creek, the principal northern tributary of the Gros Ventre River, a broad terrace (Fig. 33) 100–200 feet above the stream is very conspicuous.¹

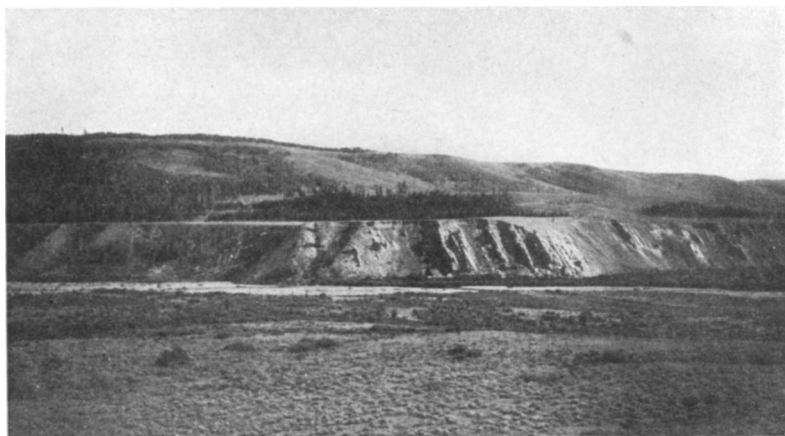


FIG. 33.—Rock-cut terrace on Fish Creek, correlated with the benches at Circle. The Cretaceous strata are nearly vertical.

To the east, in the upper part of the Wind River basin, there is a prominent terrace cut on inclined strata and again standing about 150 feet above the stream (Figs. 34 and 35). A fine remnant of it stands out just east of Circle post-office on Wind River. In each case the surface is strewn with coarse, river-deposited gravel, but the layer is only a few feet in depth. As the terrace blends into the earlier moraines of the Dinwoody and Torrey glaciers, the gravels may well consist largely of the outwash deposits of the Bull Lake stage. Again, in the vicinity of Bull Lake and Fort Washakie, a nearly smooth upland surface has been planed across tilted

¹ *U.S. Geol. Survey, Mount Leidy, Wyoming, topographic sheet.*

strata at about the same height above the creek. Other remnants (Fig. 36) may be seen along the slope of the Wind River south-

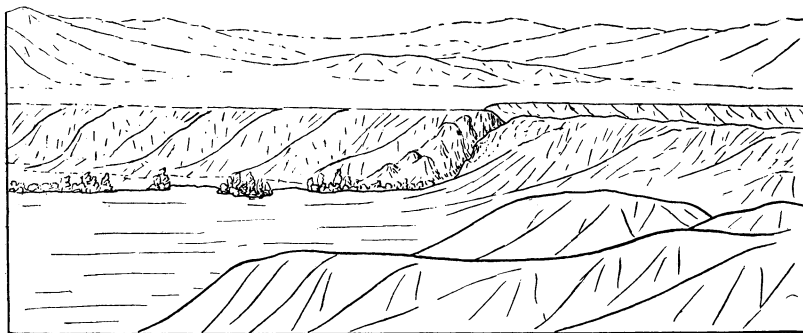


FIG. 34.—The Circle terrace near Duncan's Gorge on the North Fork of Wind River. (Drawn from a photograph.)



FIG. 35.—Rock-cut terrace of the Circle plain on Wind River at the mouth of Red Creek. Triassic (?) beds dip to the right.

west and south of Lander. This is the plain No. 1 of Westgate and Branson.¹

¹ *Jour. Geol.*, XXI (1913), 156.

Near Anchor, on the north side of the Owl Creek Range, the most conspicuous tabular hills stand about 150 feet above the present valley bottoms (Fig. 37).

In Jackson Hole the low hills scattered about the southern end of the basin are not flat-topped, but their surfaces are only gently undulating and appear to represent late mature topography of an earlier cycle. Corresponding to the tops of these hills are wide flat-bottomed valley heads in the adjacent foothills, and all about



FIG. 36.—Mesas and terraces of the Circle cycle cut across inclined Mesozoic strata in the Shoshone Indian Reservation. The higher surface at the right may represent the Black Rock cycle.

150-400 feet above the bottom of Jackson Hole. These and similar features along the west slope of the Teton Range may correspond in age and represent the Circle cycle, although the correlation at such a distance is far from assured. Northeast of the new town of Tetonia, at the north end of the Teton basin in Idaho, there are low, nearly flat-topped mesas which have been dissected to a depth of 100-200 feet by the streams which excavated the bottom of the Teton basin. These features again are of the same order of magnitude, and have the same general relations as those typical of the Circle cycle. The Circle floodplains were once two

miles wide at the type locality, but were much broader near Fort Washakie and Lander. In the somewhat more remote headwaters of the Gros Ventre valley, the terraces are only a fraction of a mile in breadth. They are distinctly older than the latest (Pinedale) stage of glaciation. The older (Bull Lake) moraines, however, rest upon the Circle terraces and blend into them in such a way as to indicate that the terraces were parts of the floodplains in the earlier glacial stage.



FIG. 37.—Circle terraces along North Fork of Owl Creek. Bedded Tertiary volcanics in the background.

Lenore cycle: Following the last distinct rejuvenation, the inner trenches of Wind River and its tributaries were excavated in the Circle floodplains (Figs. 39, 40). Although these valleys are relatively narrow in their upper reaches, they are well graded, and the floodplains are broad enough locally to accommodate ranches, as at Lenore and Circle. They expand considerably downstream.

Farther west in the Gros Ventre valley there is a similar inner valley cut in the well-defined terrace of the Circle cycle. Fish Creek has intrenched the Circle plain to a depth of 100–150 feet, and then by meandering has developed a floodplain about 1,000 feet wide (Fig. 41). On the whole, the valleys are considerably narrower here than in the Wind River basin, but the rocks

are somewhat more resistant and the region is closer to the headwaters of the streams. Westward this inner valley merges into the floor of Jackson Hole. Since the latter is now coated with recent alluvial deposits of unknown depth, it may prove to be somewhat unlike the Wind River basin in origin. If the filling is deep it may signify local warping or faulting, and the appropriate disturbance of stream gradients; but if it is thin, as I think more probable, it may be ascribed entirely to the glacial choking of Snake River.

Inner trenches of varying width, but generally similar to those farther east, are observable along Fall or "Hoback" River, down the Grand Canyon of Snake River to its lower valley near Irwin, and also along its southern tributary, Salt River, as far up as Star valley, in Wyoming and Idaho.

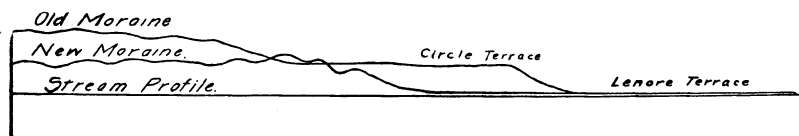


FIG. 38.—Diagram showing the relation of Circle and Lenore terraces to moraines of the (a) Bull Lake, and (b) Pinedale glacial stages. Wind River basin.

On the whole, the Lenore cycle did not go far, and resulted only in the excavation of relatively narrow valleys with slender and even interrupted floodplains, except in weak strata and along large streams. The moraines of the latest glacial stage were deposited in these valleys, showing definitely that the inner trenches were made just before the last ice advance.

It will some day be possible, through detailed local studies, to subdivide the Lenore cycle on the basis of terraces, shallow inner trenches, etc. For example, the Snake River in Jackson Hole is intrenched distinctly below the general level of the flat; at the mouth of the Grand Canyon of the Snake, the river has intrenched its gravel-strewn floodplain to a depth of 50–60 feet; and near the mouth of the Hoback River that stream has cut a trench of about the same depth through deposits of gravel into solid rock below. These features are so much more prominent in the Snake River drainage than in the Green River or Wind River basins that I am

led to think that the three systems have had somewhat different histories. Along Wind River and Owl Creek the streams are now generally intrenched 10-30 feet below the gravel-strewn terrace of the Lenore cycle, and widened according to circumstances. This has been accomplished in post-glacial time.



FIG. 39.—Crow Creek valley and Crowheart Butte, showing the broad Circle plain, beneath which the modern valley has been cut, surmounted by a monadnock carrying a remnant of an older plain. (Drawn from a photograph.)



FIG. 40.—Dry Creek valley in the Wind River basin. It illustrates the dissection, in the Lenore cycle, of the plain of Circle. The beds dip 10-15° away from the camera. The valley in the center of the view is about 150 feet deep. (Photographed by D. D. Condit, U.S. Geological Survey.)

Quaternary glaciation.—All of the mountain ranges of the district that exceed 10,000 feet in elevation bear marks left by valley glaciers of an earlier time. Indeed, a few small bodies of ice still exist in the deep cirques of the Teton, Shoshoni, and Wind River ranges. By glacial action the mountain crests have been excavated in the characteristic way, and the canyons have been modified

in varying degree. In some cases the ice descended as far as the foothills of the range, and a few of the largest ice-tongues expanded out upon the adjacent plains. It is not my purpose to map or describe in detail the glacial phenomena of each range, but rather to discuss the general nature and course of events in the district as a whole, using individual cases for illustrations and as evidence.

It is clear that the time which has elapsed since glaciers first appeared in this region has been very long, and the time since they vanished very short. On the one hand, there are deposits of till that have been so deeply eroded that only remnants of them now



FIG. 41.—The floodplain of Fish Creek in the Mount Leidy highlands. Benches on the left are remnants of the older (Circle) floodplains, cut across inclined beds.

remain, and the intervening canyons are hundreds of feet deep in solid rock. On the other hand, some of the glacial features are as fresh as if they had been made within historic times—the moraines almost untouched by erosion, the boulders essentially unweathered, the lakes not yet filled, and the striated rock surfaces still conspicuous. In the older drift little if any trace of original glacial topography remains, and most of the surface boulders have disappeared either through weathering or through burial by eolian dust. An examination of only one or two valleys in the district might prompt the conclusion that there were two and only two stages of

glaciation; but, after having studied the deposits of more than forty-five Pleistocene glaciers, distributed over a large part of western Wyoming, I find it no easy task to reduce the facts to such comfortable simplicity. Indeed, if disposed to support arbitrarily the hypothesis that there have been many successive advances of glaciers, I could, by selecting cases, arrange a graded series leading by almost imperceptible steps from the least modified glacial deposits which have been practically unaffected by post-glacial changes, to those which have lost most of their glacial characteristics and have been eroded to isolated remnants. Before discussion of the question of successive glacial stages some general considerations need attention.

The glacial features in the several valleys differ from each other in many respects, among which the following are important: (*a*) the depth to which moraines have been intrenched by streams, and the extent to which they have been reduced in area; (*b*) the degree of preservation of distinctive glacial topography; (*c*) the closeness of relation of the moraines to modern valleys and their terraces; (*d*) the progress of weathering of glaciated rock surfaces and of the boulders upon the moraines; (*e*) the depth of soil, particularly of loess, on the moraines.

These attributes are influenced by more or less variable conditions and one should be prepared to find drift deposits of essentially the same age, changed much in some cases and little in others. Lateral moraines resting upon soft clays may be rapidly destroyed through the growth of gullies, while moraines planted firmly on the hard Paleozoic or pre-Cambrian rocks suffer only trivial erosion in the same length of time. Drift plastered along steep slopes may be largely denuded while contemporaneous moraines lying upon interstream plateaus retain their original topography. Ponds without inlets apparently are filled much more slowly than those entered by streams, especially if those streams are eroding soft materials. Where the climate is dry, as in the Wind River basin, it is probable that the boulders on the moraines would show fewer signs of decay than those in the moist forests on the west slope of the Teton Mountains, and also that soil and loess would accumulate more rapidly in the latter region,

because the vegetation serves to entrap the dust from the western basins.

This prelude to the general discussion of Quaternary glaciation is given in order to show that the satisfactory correlation of the different drift deposits and other glacial phenomena of the district is a difficult matter, calling for critical interpretation. In order to eliminate the effect of variable conditions, it is necessary so far as possible to compare only cases where the environment has been generally similar; and I may add that a large amount of additional information from the field is needed.

In many canyons glacial drift of two distinct ages can be recognized easily, and it seems to me there is sufficient evidence that the later stage of glaciation is divisible into two quite distinct episodes. There are a few facts which hint at a still older or fourth stage, but they may be otherwise interpreted. Without attempting an actual correlation, the three sets of deposits may be compared in general state of preservation to the late and early Wisconsin, and the Illinoian or the Kansas drift sheets in the Mississippi Valley region. In explanation of this view I shall describe the characteristics of the drift and other glacial features of the various stages here suggested, beginning with the most recent.

Pinedale stage: The youngest moraines, which for convenience may be called the Pinedale drift, are conspicuous in the vicinity of Torrey Lake and Bull Lake in the Wind River valley, Osborn ranch on Green River, Jenny Lake and Taggart Lake in Jackson Hole, around each of the large lakes near Pinedale on the southwest side of the Wind River Range, and also in many other valleys of the district. They are very rough and fresh in appearance, being covered with bowlders which themselves show but little effect of weathering (Fig. 42). Many of the bowlders of hard, fine-grained rocks show polished or scratched surfaces, even though fully exposed to the weather; and in the cirques above the moraines such surfaces, bare or now covered only with moss, are abundant. The terminal moraines are generally intact and the lateral moraines continuous, save where unusual conditions have subjected them to abnormally rapid erosion. Lakes and ponds which contain but little post-glacial filling are characteristic features of these newest

moraines, and even those lakes which lie in the courses of the main creeks have been only slightly reduced by the building of deltas or the cutting of outlets.

Bull Lake stage: The next older moraines, which I have compared with the early Wisconsin drift of Illinois, will be called the Bull Lake drift, from the locality of that name on the north slope of the Wind River Range. The deposits of this stage are definitely related to the terraces of the Circle erosion cycle in that they blend



FIG. 42.—Hills in the latest terminal moraine at the lower end of Bull Lake. The prominence of bowlders is characteristic.

into the gravel-strewn benches as modern moraines blend into their outwash deposits. The moraines are still largely intact, and by using a little imagination to supply gaps, they can be mapped in their original extent. In protected places, as on flat uplands, the topography is still visibly morainic, consisting of orderless humps and hollows. That the Bull Lake drift is nevertheless distinctly older than the Pinedale drift seems to me to be indicated by the following facts: (a) bowlders are by no means as abundant upon the

surface as they are on the Pinedale moraines, and those which remain show plainly the effects of weathering;¹ (b) lakes are rare or absent, but hollows filled with peat mark the sites of many that have

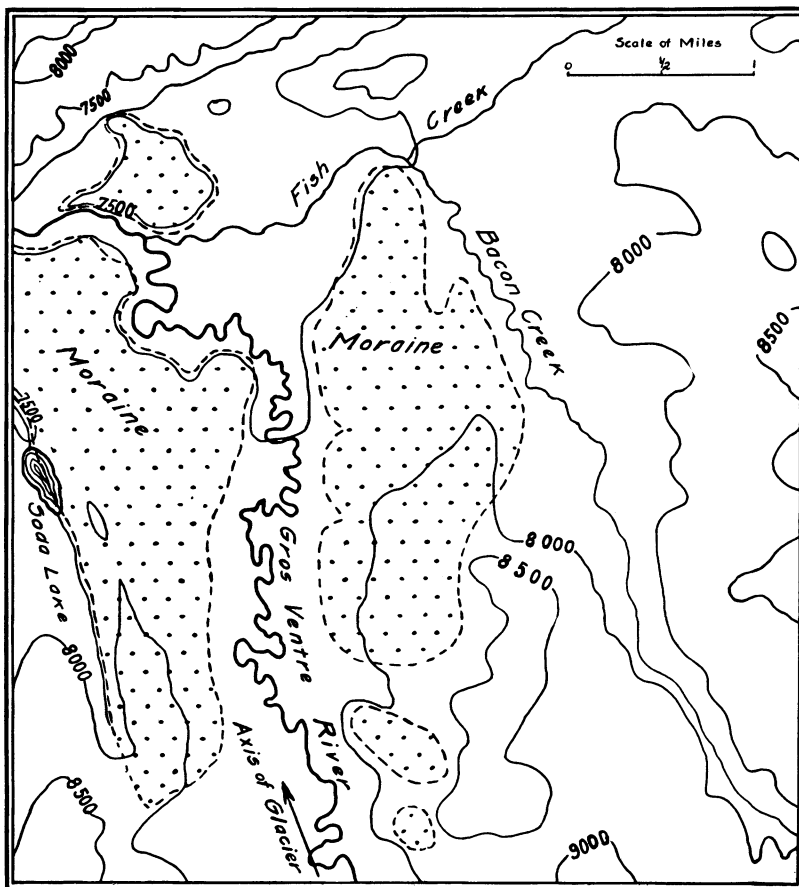


FIG. 43.—Sketch map showing the dissection of the old moraine (Bull Lake [?] stage) at the junction of Fish Creek and the Gros Ventre River.

disappeared; (c) the principal creeks have cut not merely sharp ravines but rather wide flat-bottomed valleys through the terminal

¹ A fact possibly related to the weathered condition of the older drift is the observed scarcity of cedar trees on the older moraines at Bull Lake, while such trees are so abundant on the adjacent new moraines that the latter appear much darker.

moraines, and the tributaries have largely dissected the lateral moraines into short pieces.

The frayed character of the terminal moraines is indicated in Figs. 43 and 44. At the mouth of the DuNoir River near the west

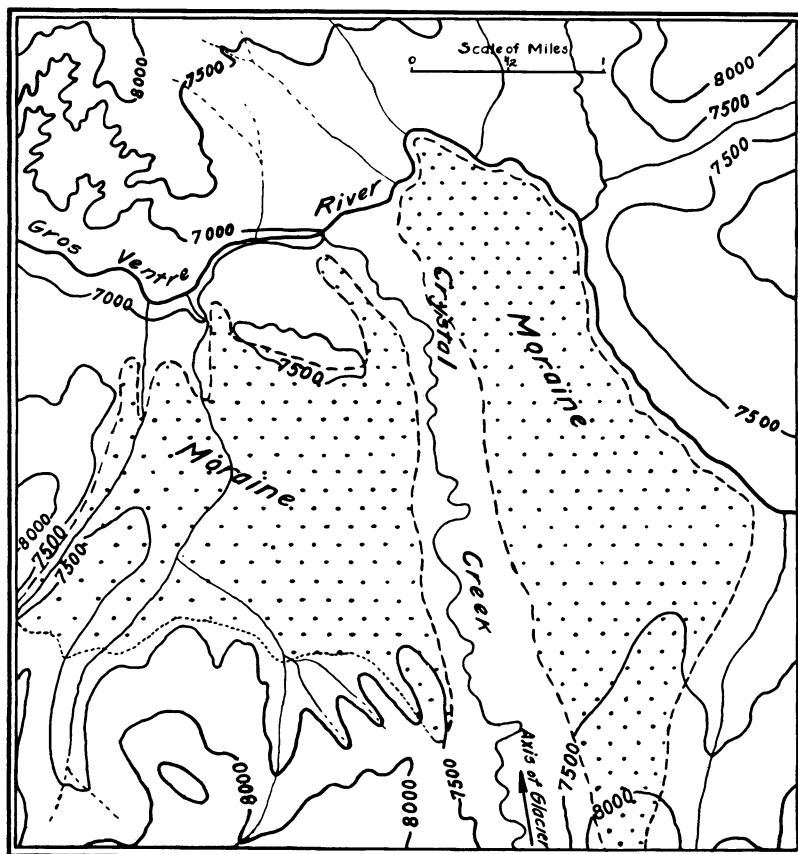


FIG. 44.—Sketch map showing the dissection of the old moraine (Bull Lake [?] stage) at the mouth of Crystal Creek, Gros Ventre Range.

end of the Wind River basin, the position of the old terminal moraine is occupied by a spacious river floodplain; nevertheless, the old lateral moraine, now 200–300 feet above the river, is still largely intact and can be readily identified by its hummocky topography. On the north side of Dell Creek, on the south side

of the Gros Ventre Range, two well-defined lateral moraines, without any terminal junction, have been beheaded upstream by the excavation of the inner valley of the modern Shoal Creek. On account of the much more rapid destruction of lateral moraines where they rest on steep slopes in soft rocks, the old lateral moraine at Sunday Peak on the Gros Ventre River has been almost completely destroyed by the development of numerous short ravines in the Cretaceous shale.

Some of the best examples of the Bull Lake moraines are to be found near the mouth of Crystal Creek (Fig. 43), and near the mouth of Fish Creek (Fig. 44) in the Mount Leidy quadrangle, along Green River south of Kendall in the Gros Ventre quadrangle, and the older moraines of Bull Lake, DuNoir River, and Dinwoody Creek in the Wind River basin. At the mouth of Teton canyon, on the west slope of the Teton Range, distinct lateral moraines have been cut into short lengths and yet they are still connected downstream by the eroded remains of a bulbous terminal moraine. On the basis of similarity of conditions these deposits are correlated with the moraines of the Bull Lake glacial stage.

The glaciers of the Bull Lake epoch were in most instances longer than those of the Pinedale epoch. Thus, on Crystal Creek the difference in length was about four miles, on the Gros Ventre River about nine miles, and on Green River apparently twenty-five miles. On the north slope of the Wind River Range, however, there seems to have been but little difference in length, and the Pinedale moraines in the valleys of Bull Lake and Dinwoody Creeks were even advanced a fraction of a mile farther than the older terminal moraines.

Buffalo stage: Certain other glacial deposits, which are evidently very much older, are readily differentiated. These may be called the Buffalo drift, from their typical occurrence along Buffalo Fork of Snake River. The deposits which appear to represent this stage now exist only in the form of remnants on flat-topped divides or isolated hills, or on spurs along valley slopes. Such surfaces have already (p. 312) been correlated as belonging to the Black Rock cycle of stream erosion. The grouping of these remnants suggests that they are parts of originally more extensive bodies

which have since been cut to pieces by the growth of canyons. The canyons have been excavated, not only through the drift sheet itself, but 200-1,000 feet in the underlying rock. Thus the deep valley of the north fork of Teton River has been cut almost entirely since the deposition of the Buffalo drift, for the river now has a V-shaped gorge devoid of glacial features in the horizontal flows of rhyolite, and the old drift caps a flat-topped divide on either side (Fig. 45). The canyon of Buffalo Fork, about fifteen miles above its junction with Snake River, is a similar trench sunk about 1,000 feet into the Cretaceous (?) shales which underlie the extensive deposits of old drift.

As should be expected, the ancient moraines have been much more extensively destroyed where they rest upon weak strata in proximity to an actively degrading stream. For example, in the



FIG. 45.—Diagram of the canyon of Teton River southeast of Ashton, Idaho, showing the present relations of the oldest (Buffalo) drift.

valley of the Gros Ventre River about seventeen miles above its mouth, there is a remnant of till identified by striated subangular boulders exposed in a new roadway. The granitic and other distinctive rocks entering into the composition of this material indicate that the ice-tongue came originally from the Wind River Range, and probably from the canyon of Green River. Yet no trace has thus far been found of the old lateral moraines.

Uncorrelated drift deposits greatly reduced by erosion were observed on the high divide between Leigh and Teton creeks, on the west slope of the Teton Range. There the glacial origin of two or three little bodies of boulder-clay is proven by the presence of striated stones, and other characteristics of till, but their age is not clear. One of the remnants occupies a saddle in an undulating ridge which separates two deep canyons. Another remains on the shoulder of a spur dividing the forks of a canyon 800 feet deep.

It is evident from their situations that they were deposited before the adjacent canyons were cut. It is also patent that they are but the last relics of the original moraines, of which the outlines and catchment areas can no longer be seen.

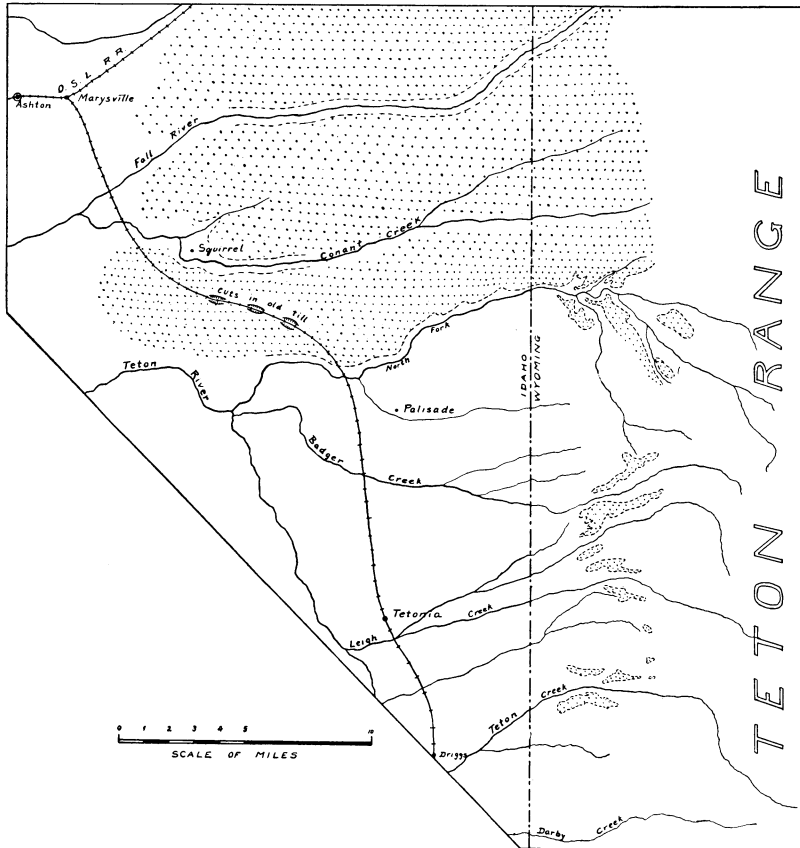


FIG. 46.—Sketch map showing distribution of remnants of old (Buffalo) drift on the northwest side of the Teton Range.

They may be regarded as drift deposited by a small glacier of the Buffalo stage from the slope between Leigh and Teton creeks, and subsequently almost destroyed by the spreading tributaries of the larger canyons. It is also possible that they may represent an earlier glaciation.

Cirques of the Buffalo stage are no longer to be identified with confidence, and it is now uncertain whether the glaciers were of the valley type or parts of an ice-cap. In most cases even the general outline of the ice-mass is uncertain. But few traces of morainic topography now remain in the drift of this age, because most parts of the region have been dissected to maturity by the growth of valley-systems. This condition is clearly shown on the broad sheet of till along the new branch of the Oregon Short Line between Marysville and the north fork of Teton River in eastern Idaho (Fig. 47). Nevertheless, on some of the broadest plateaus, where

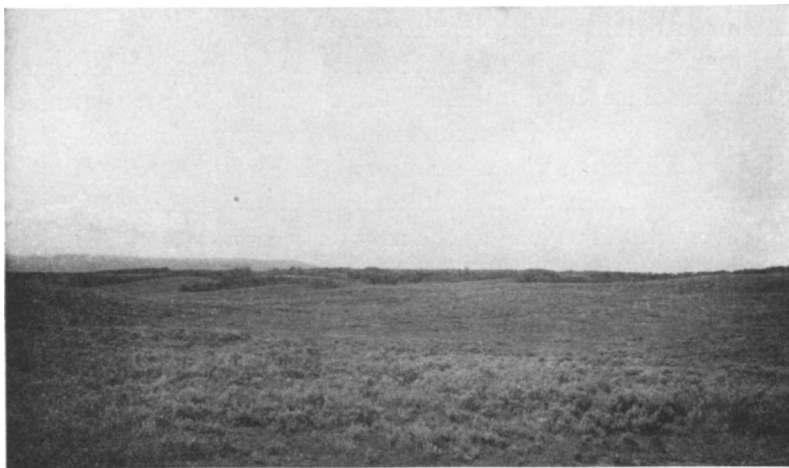


FIG. 47.—The present topography of the ancient till sheet (Buffalo) south of Conant Creek on the northwest slope of the Teton Range.

relief is still slight, there are shallow depressions filled with peat, or still containing marshy lakes. Such features are to be found twenty miles east of Ashton, Idaho, and near the branching of Buffalo Fork of Snake River.

The surface of the old drift in the western half of the region is generally smooth and almost devoid of boulders. This probably is due not so much to the decay of boulders as to their burial by the eolian deposition of loess in that district to a depth of from two to five feet. Boulders of granite on the isolated hills of sedimentary rock south and east of Kendall in the Green River valley are outside

the zone of loess deposition, and are now so much weathered that the large feldspar crystals protrude and some of them can be picked out with the fingers. The coarse, unassorted, and unstratified character of these deposits suggests that they may be glacial; and their isolated situation indicates that they have suffered greatly from erosion. They are tentatively referred to the Buffalo drift.

Glacial scratches are of course found only on bowlders of resistant rock and even then only where they have been effectually insulated from the action of the weather. Striated bowlders of Buffalo age were found in considerable numbers in the new railroad cuts, southeast of Ashton, Idaho. In that locality the old drift is more or less cemented by lime carbonate.

From these facts it seems certain that the changes which have taken place since the deposition of these bodies of till are very much greater than those which occurred between the making of the Bull Lake and Pinedale series of moraines. The conditions imply that the period between the Buffalo and the Bull Lake glacial stages was several times as long as the next succeeding interglacial interval, and many times longer than the post-glacial epoch.

Glacial drift comparable to the Buffalo moraine in its relations seems to cover most of the plateau of Yellowstone Park. Even in the seventies, as a member of the Hayden Survey, Holmes¹ recognized the fact that the deep gorge of the Yellowstone must have been cut after the deposition of the glacial drift which mantles the surrounding plateau. For some unaccountable reason, this early recognition of drift much older than the fresh moraines in the Rocky Mountain region seems to have remained unnoticed and is not mentioned even in more recent comprehensive papers on the geology of Yellowstone Park itself.

Although its full extent is no longer traceable, it is evident that the Buffalo ice covered a much larger area than the glaciers of the Bull Lake and Pinedale epoch. The latter were valley glaciers, which in but few instances pushed beyond the mouths of the canyons in which they developed. The Buffalo ice of the Teton back-slope, and probably also of Yellowstone Park, spread far

¹ W. H. Holmes, "Glacial Phenomena in the Yellowstone Park," *Am. Naturalist*, XV (1881), 203-8.

out upon plateau surfaces at least twenty-five miles from the mountains.

Summary of glaciation: From this discussion a few generalizations arise. All of the principal ranges of the district, except perhaps the Owl Creek Mountains, were glaciated during the Quaternary period. There were certainly two stages of glaciation separated by a long period of time, and the later of these can again be resolved with some confidence into two. A few facts slightly suggestive of a fourth epoch, still older than the others, are quite inconclusive. The glaciers of the Pinedale and Bull Lake stages were ordinary valley glaciers, which ran but little beyond the mountain fronts and rarely deployed outside their individual canyons. In most valleys, the younger of these glaciers were shorter than the older, although in a few instances they were not. In the Buffalo stage, however, a large piedmont glacier spread westward from the north end of the Teton Range, and Yellowstone Park appears to have been almost entirely buried under a mass of ice.

There is much resemblance between the sequence of glacial events in this district and that described by Atwood in the San Juan Mountains of Colorado. Although full confidence should not be placed in a long-distance correlation made without indulging in a more detailed and comprehensive study of the Rocky Mountains, it may be suggested that the deposits characteristic of Atwood's "Uinta," "Bighorn," and "San Juan" stages correspond in many respects to those of the Pinedale, Bull Lake, and Buffalo stages in western Wyoming. The Pinedale and "Uinta" moraines are alike in being very fresh and almost uneroded. The Bull Lake moraines resemble somewhat those of Atwood's "Bighorn" stage in being notably eroded although still traceable, but the Bull Lake moraines are rather better preserved. Like the till of Atwood's "San Juan" stage, the Buffalo moraines have been intrenched 500-1,000 feet and so reduced in area that at best their original forms can be but rudely traced, and in some places they constitute mere remnants which suggest nothing of former distribution or derivation.

Work of gravity with the aid of weathering.—Here, as in all regions of sharp relief, the steeper slopes are wasting away under the attacks of the weather; and the resulting débris has been making

its way down the slopes by rolling, slumping, and creeping. No doubt these processes have all been in operation, at varying rates, throughout the erosion history of the district. There is but little recognizable evidence of them, however, relating to topographic stages farther back than the Black Rock cycle of erosion.



FIG. 48.—Talus glacier in a cirque on the north side of Sheep Mountain, near the head of Green River.

The accumulations of talus are greatest above the timber-line, and beneath the most resistant cliff-forming strata. In the lower parts of glaciated valleys, the waste slopes have been largely swept away, except in so far as they have begun to redevelop since the ice disappeared. In a few cirques, talus glaciers, such as those described by Cross and Howe¹ in the San Juan Mountains of Colorado, have

¹ *U.S. Geol. Survey, Prof. Paper 67*, 1909.

been formed. On the northeast side of Sheep Mountain at the northwest end of the Wind River Range there is a good example showing the tongue-like form and surface corrugations (Fig. 48). Rock-falls have been observed where outcrops of the massive Big-horn dolomite have given way suddenly, perhaps because of the removal of the support previously given by the mass of glacial ice in the valley. Figs. 49 and 50 show two rock-falls of this kind in the Teton and Gros Ventre ranges. More numerous landslides of the commoner type, developing in soft or unconsolidated rocks, are observable here and there along the slopes of the canyons in the



FIG. 49.—A rock fall in Paleozoic dolomite near the head of the Gros Ventre River

district. There is a particularly large and fresh slide near the head of Dell Creek on the south side of the Gros Ventre Range. Perhaps the most novel of the many landslides in this region are the earth-flows which are especially characteristic of the Gros Ventre valley (Fig. 51). They depend upon steep slopes in soft argillaceous material such as constitutes the Jurassic, Cretaceous, and Tertiary systems. The most recent of these flows I have described in another paper,¹ and for this reason further mention of them may be omitted here.

The landslides and talus deposits are clearly of various ages. A few have been made within recent years. Many others are

¹ *Bull. Geol. Soc. Am.*, XXIII (1912), 487-92.

covered with forest and must be some generations or centuries old, although nearly all of their topographic features and forms are still preserved. Still others have been scarred by gullies to such a degree that they are now recognizable only upon somewhat careful examination. There are many places in which landslides of two or three distinct ages may be seen side by side on the same valley slope.

Wind work in the Quaternary period.—The climate of the entire region is moderately dry, and in the centers of the large basins it is decidedly arid. Under such circumstances the wind is admittedly

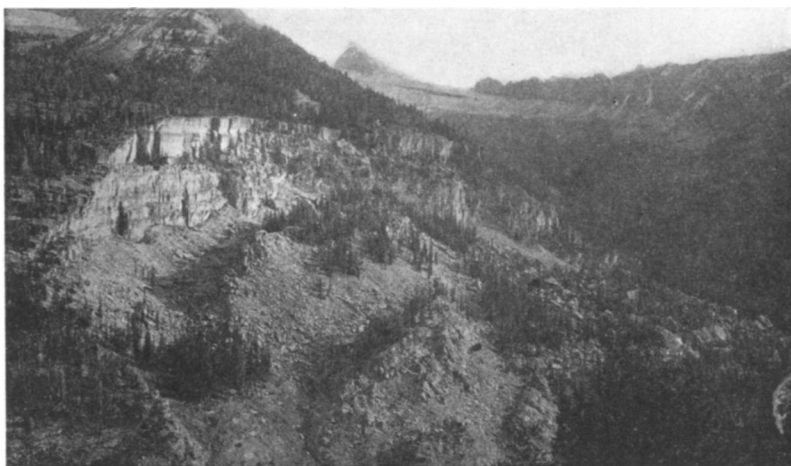


FIG. 50.—A rock-fall in the canyon of Darby Creek, Teton Range

an important agent in shaping topographic forms. The characteristics of its work are, however, greatly influenced by the varying conditions in different parts of the district. Thus, in the hot, dry central part of the Wind River and Green River basins, the erosive action of the winds can be observed daily. Bunches of sagebrush and greasewood are left perched on hillocks, where the silt has been blown out from around them by the wind. Protruding ledges of rock have been carved by the sand-blast into the usual fantastic pillars, mushroom forms, and honeycomb surfaces. Many of the smooth slopes along the sides of the valleys are swept so clean that every lamina of rock may be measured or traced for yards and even miles along the outcrop. The smooth tops of many mesas and

terraces out in the bad lands coincide with the more massive and hence resistant layers of sandstone from which the wind has completely swept off the soft beds of sandy clay.

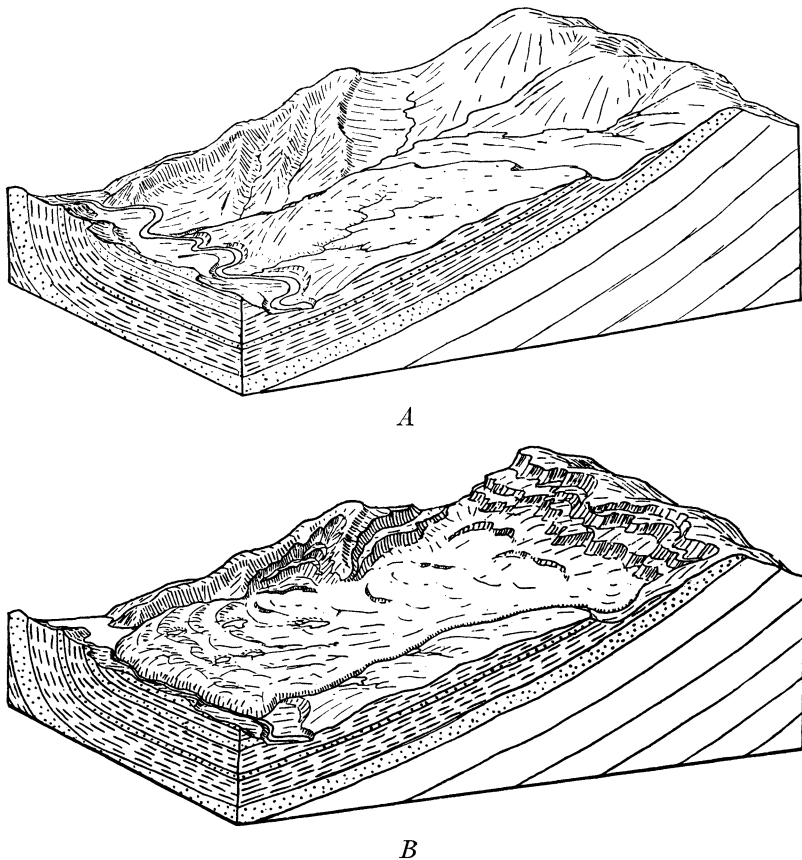


FIG. 51.—Diagrams to illustrate the formation of an earth-flow such as the “Gros Ventre Slide” of 1909-11: (A) before the action began; (B) after the slide took place. (From *Bull. Geol. Soc. Am.*)

On the other hand, wind erosion must necessarily have wrought but slight effects upon those parts of the mountain sides that are protected by forests, and but little more upon their rocky summits. The timber belt, constituting Merriam’s¹ Hudsonian and Canadian

¹ C. H. Merriam, “Life Zones and Crop Zones of the United States,” *Bull. 10, U.S. Geol. Survey*, 1894.

life zones, and the sagebrush and aspen slopes of his Transition zone, are apparently, however, the sites of considerable eolian deposition. For example, along the grassy and forested western slope of the Teton Range, a thick structureless soil mantles the surface. Occasional exposures show that it is from two to twenty feet deep, entirely free from sand, gravel, or boulders, and of a yellowish or buff color. The chemical analysis given in Table III shows that it is similar in composition to the loess of the Mississippi and Missouri valleys.

TABLE III
TABLE OF ANALYSES OF LOESS*

	1 Teton Mountains, Wyoming	2 Iowa	3 Missouri
SiO ₂	72.04	72.68	74.46
Al ₂ O ₃	12.37†	12.03	12.26
Fe ₂ O ₃	3.38	3.53	3.25
FeO.....	0.37	0.96	0.12
TiO ₂		0.72	0.14
P ₂ O ₅		0.23	0.09
MnO.....		0.06	0.02
CaO.....	1.21	1.59	1.69
MgO.....	1.22	1.11	1.12
Na ₂ O.....	1.83	1.68	1.43
K ₂ O.....	2.58	2.13	1.83
H ₂ O.....	3.15	2.50‡	2.70
CO ₂	trace	0.39	0.49
SO ₃		0.51	0.06
C, organic.....		0.09	0.12
Undetermined.....	1.85		
	100.00	100.21	99.78

* Analyses 2 and 3 are taken from a paper on "The Driftless Area" by T. C. Chamberlin and R. D. Salisbury, *6th Ann. Rept., U.S. Geol. Survey*, 1885, p. 282.

† Including TiO₂, P₂O₅, MnO, etc.

‡ Contains H of organic matter. Dried at 100° C.

1. Loess overlying old drift, one mile east of Alta, Teton Creek, Teton Mountains, Wyoming. Sample taken two feet below the surface. Analyst, W. C. Wheeler, U.S. Geol. Survey, 1912.

2. Loess near Dubuque, Iowa.

3. Loess from river bluff at Kansas City, Missouri.

It is suggested that this widespread veneer of loess consists largely of the dust blown by the westerly winds from the dry regions of Oregon and Idaho and strained out by the vegetation on the mountain slopes. It is significant that such deposits are not characteristic of the Wind River and Green River basins, which

are apparently subject to the removal of dust rather than to its accumulation.

Sand dunes, which might be expected in the driest parts of the district, appear to be rare, although a few were observed along the middle course of Green River. This tends to confirm the view that in this region the dominant phase of eolian activity is erosive.

SUMMARY OF CONCLUSIONS

Divested of details and qualifications, the history of the district may now be reviewed in general terms. About the close of the Cretaceous period, the entire region was probably a monotonous plain underlain by unconsolidated sediments. Soon thereafter, tangential forces within the earth's crust produced a series of moderate folds, trending northwest and southeast. The process of folding tended to produce a series of mountain ranges and basins corresponding to the anticlines and synclines; but the uplifts were certainly being eroded even while they were growing, and after the disturbance ceased they continued to be worn down until the surface became a well-dissected mountainous or hilly region interspersed with wide, relatively flat basins.

In the Wasatch or Lower Eocene epoch, terrestrial sediments began to accumulate in the lowlands, probably in response to mild warping movements and perhaps climatic changes, which disturbed the activities of the previously graded streams. These sediments were distributed chiefly by rivers, but doubtless in part by the wind, and some seem to have lodged in lakes and playas. Sedimentation thus continued with but little interruption under a rather warm, subarid continental climate until some time after the early Oligocene. Early in this sedimentary cycle there were volcanic eruptions in the western part of the district, during which acidic lava flows and occasional beds of ash were deposited; but the much more extensive eruptions of the Absaroka Range took place later. The grassy plains of the time were occupied by ancestral horses, cloven-hoofed ungulates, rodents, gigantic titanotheres, and their appropriate carnivorous enemies.

Somewhat later, probably near the middle of the Miocene epoch, the district was notably warped and locally faulted, in part

along the structural lines established at the close of the Cretaceous, but in part at variance with them. It is probable that this mid-Tertiary disturbance involved also a general elevation which left the region above base-level, and therefore subject chiefly to erosion rather than to sedimentation.

From the mid-Tertiary revolution down to the present time, the history of western Wyoming is a chronicle of denudation. It is believed that at all times the master streams of the region controlled the general shaping of topography, although the effects of stream erosion were modified in important details by mountain glaciers, by the wind, and by slumping. The progress of general stream erosion was evidently not steady, but was interrupted by successive elevatory movements or other changes which compelled the readjustment of stream activities. In the earliest of the erosion cycles of which good evidence still remains, the region seems to have been generally reduced to a peneplain even where the rocks were tolerably resistant. This plain is believed to have been established during the Pliocene epoch.

Later cycles followed each other with more rapidity—or more probably we read the later chapters in more minute detail. They were apparently caused in large measure by general uplifts of the Rocky Mountain region, although they may well have been influenced in noteworthy degree by climatic changes, river piracy, and other modifying causes. While these erosion cycles and interruptions were in progress, there occurred certainly two, and almost surely three, distinct advances of glacial ice in the mountains, followed by as many retreats and perhaps complete disappearances. Between the glacial stages the streams continued their work and sank their valleys through the moraines and into the underlying rocks. Since the latest glacial advance only slight topographic changes have been made.